

Rethinking Packaging Materials

System Alignment, Emissions Exposure and Transition Risk



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Executive Summary

The Packaging Sustainability Challenge India's packaging sector faces a structural inflection point. Recycled content mandates are expected to escalate from 50% to 80% by 2028 for certain materials, which can significantly increase the EPR compliance cost. For FMCG companies, packaging decisions made today will determine regulatory risk exposure, cost structures, and competitive positioning for the next decade. This report assesses packaging materials across three critical dimensions: circularity under current Indian recovery systems, lifecycle environmental impacts, and total cost of ownership under evolving regulations, to provide evidence-based guidance for material selection and portfolio transition.

Key Findings

1. Circularity performance varies significantly across materials.

- PET scores between 70–80, HDPE between 63–70, while LDPE (35–40) and multi-layer plastics (25–30) remain structurally misaligned with current recovery systems.
- PET (70-80) and HDPE (63-70) are well-aligned with India's informal recovery systems and can support closed-loop recycling with quality improvements
- Multi-layer plastics (25-30) and LDPE films (35-40) face fundamental structural barriers, such as low scrap value, no recycling pathways, and complete virgin material dependence
- Implication: Materials scoring below 50 will require continuous subsidies or should be phased out; optimisation efforts should focus on materials scoring above 60

2. Low Circularity Drives High Compliance Costs

- MLP shows 15-20% higher total cost of ownership than PET over 5 years, despite lower material weight, driven by recurring EPR certificate purchases and end-of-life processing costs
- As recycled content mandates tighten (Category I: 50% → 80% by 2028), materials dependent on virgin inputs face compounding cost exposure
- Implication: Current "cheap" packaging may become expensive; TCO modelling essential for 3+ year procurement decisions

3. Alternative Materials Are Not Universal Solutions

- Bio-based and compostable alternatives address specific use cases where conventional plastic recovery fails (high-leakage applications, short-use-life formats)
- Economic viability is limited by cost premiums (15-60% vs conventional), infrastructure gaps (composting facilities), and behavioural dependence
- Implication: Alternative materials should be deployed strategically, not universally; require system alignment to deliver intended benefits

Strategic Recommendations For High-Performing Materials (PET, HDPE)

- ✓ Prioritise closed-loop recycling quality improvement
- ✓ Secure recycled content supply chains now
- ✓ Design for recyclability For Low-Performing Materials (MLP, LDPE)
- ✓ Develop phase-out roadmaps (18-24 months)
- ✓ Pilot mono-material alternatives
- ✓ Avoid new capital commitments

Who Should Read This Report

- Sustainability & ESG Teams: Regulatory roadmap, material assessment framework, transition strategies
- Procurement & Supply Chain: Total cost of ownership analysis, supplier implications, timeline planning
- R&D & Product Development: Alternative materials overview, design-for-circularity principles
- Finance & Risk Management: Compliance cost modelling, capital allocation for transitions
- C-Suite: Strategic implications, competitive positioning, regulatory risk exposure

Adyra ESG Technologies provides:

- EPR Compliance Strategy & Roadmaps – Gap analysis, timeline planning, certificate procurement strategy
- Traceability System Design – QR code/barcode implementation aligned with 2025 mandates
- Regulatory Risk Assessment – State-level compliance variance analysis, scenario planning
- Recycled Content Supply Chain Mapping – Supplier identification, quality verification, volume forecasting

Global Plastic Consumption, Waste and Emissions



Plastics have become one of the defining materials of the modern economy. Global plastic production has increased from a few million tonnes in 1950 to more than 450 million tonnes annually today. Under current trends, the production is projected to approach one billion tonnes by 2040 if current trends continue (OECD, 2022). This expansion has been driven by plastics' low cost, durability, and versatility, making them integral to packaging, construction, automotive, electronics, and consumer goods.

Packaging represents the most significant use of plastics globally, accounting for approximately 40–42% of total demand. Its dominance is not only a matter of volume, but also of impact. Packaging is typically short-lived, rapidly discarded, and highly visible in waste streams. As production has expanded faster than waste management capacity, packaging has become a central contributor to plastic pollution, greenhouse gas emissions and resource inefficiency.

Lifecycle assessments estimate that plastics generated

approximately 1.8 gigatonnes of CO₂-equivalent emissions in 2019, representing around 3.4% of global greenhouse gas emissions. Without additional mitigation, emissions from plastics are projected to more than double to approximately 4.3 Gt CO₂e by 2060 (OECD). These emissions occur across the full lifecycle, from fossil feedstock extraction and polymer production to conversion, transport and end-of-life treatment.

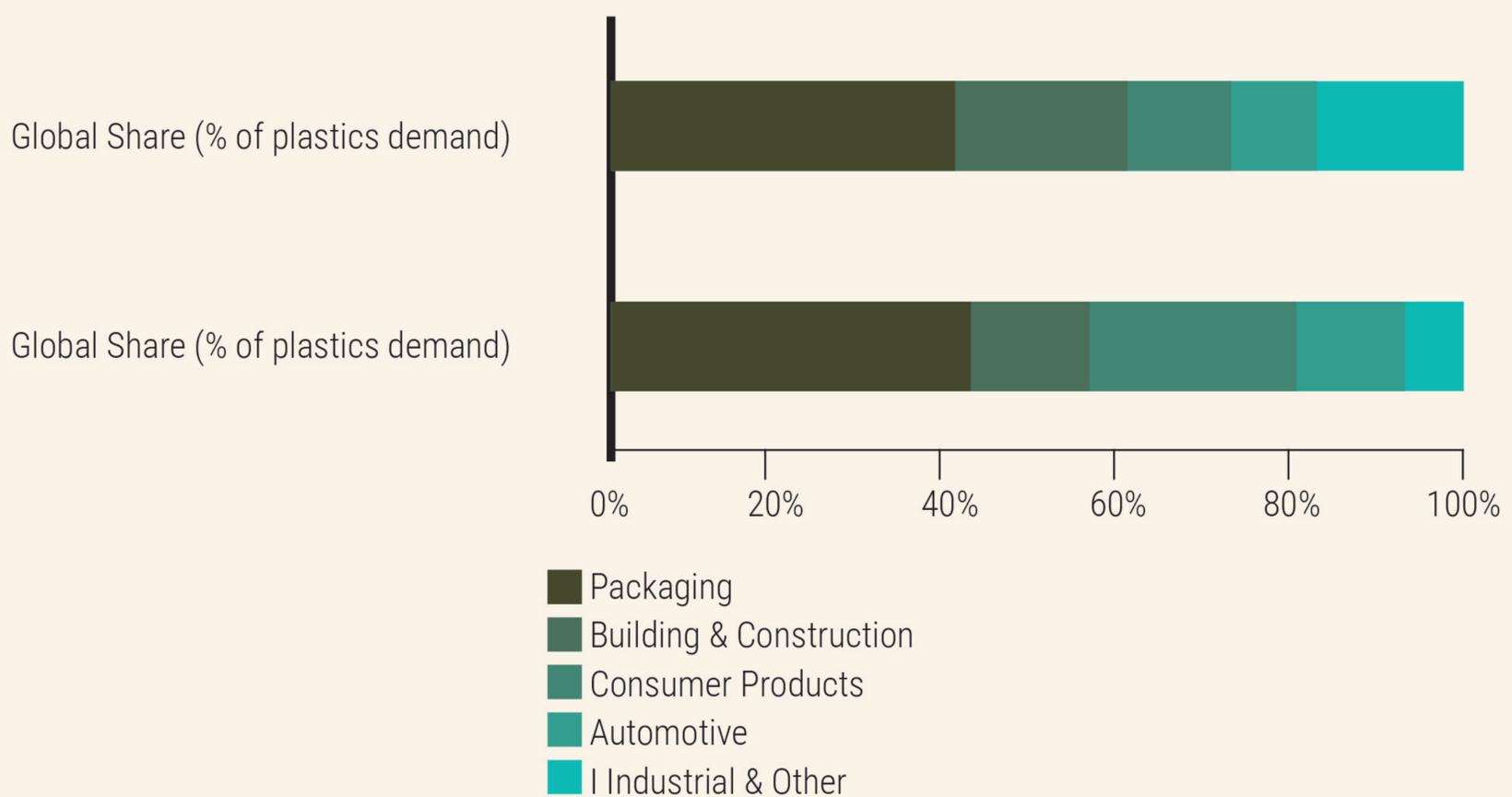
Mismanaged plastic waste introduces a further challenge. Once released into the environment, plastics persist for decades and fragment into microplastics that accumulate in soils, freshwater and marine ecosystems. Despite technological advances, less than one-fifth of global plastic waste is effectively recycled, while the remainder is landfilled, incinerated or leaked into the environment (OECD). These dynamics highlight the need to reassess not only how plastics are managed at end-of-life, but how packaging materials are selected in the first place.

Single Use Packaging

Globally, packaging is the single largest user of plastics, accounting for roughly ~40–42% of total plastics demand, which is driven by flexible films, bottles and single-use containers. Other major sectors are construction, automotive, electrical/electronic goods and textiles, but packaging dominates both production volumes and end-of-life challenges because of its short lifetime. Similarly, in India, the plastics industry is growing rapidly, and

packaging accounts for a substantial share of domestic plastic use. India's plastic consumption has grown alongside its economic development and urbanisation. India generates millions of tonnes of plastic waste annually, driven by rising demand for packaged goods, e-commerce and lifestyle products. Growth in the informal sector and rapid urban expansion have further increased the use of plastic.

Sector Wise Demand for Plastic Product



India mirrors global trends while exhibiting distinct system characteristics. Rapid urbanisation, rising incomes, growth in packaged food consumption and expansion of e-commerce have driven a sharp increase in plastic use,

particularly in packaging. Flexible packaging formats such as pouches, sachets and multilayer films are especially prevalent in the Indian FMCG sector due to their low material cost, light weight and convenience.

Key Takeaway

Flexible packaging (sachets, pouches, MLP) dominates FMCG but has the lowest recovery rates in India's informal-sector-driven waste system. This creates a material-specific compliance risk as EPR targets escalate

However, these same attributes create systemic challenges. Small size, short use life and composite material structures make many flexible packaging formats difficult to collect, segregate and recycle. India's waste management ecosystem is predominantly informal and market-driven. Materials are recovered not because they are technically recyclable, but because they have sufficient post-use

economic value. Packaging formats that lack such value are far more likely to exit the system as waste. As a result, India experiences high levels of environmental leakage from packaging formats that are structurally misaligned with its recovery ecosystem. This reality has shaped the evolution of policy responses aimed at addressing plastic waste at scale.

Policy Evolution: Plastics Rules in India

India has progressively strengthened its legislative framework governing plastics and plastic waste. The Plastic Waste Management (PWM) Rules form the principal legal framework in India for regulating plastic waste and its environmental impacts. Originally notified on 18 March 2016 under the Ministry of Environment, Forest and Climate Change (MoEFCC), the Plastic Waste Management Rules, 2016 were established to strengthen the mechanisms for segregation, collection, processing, recycling, and disposal of plastic waste in an environmentally sound manner, and to minimise plastic pollution at source. To strengthen and operationalise the EPR framework specifically for plastic packaging, the Plastic Waste Management (Amendment) Rules, 2022, were notified by the MoEFCC on 16 February 2022 through Schedule II – Guidelines on Extended Producer Responsibility for Plastic Packaging

Under the amended rules, EPR guidelines require producers, importers and brand owners (PIBOs) to plan and implement strategies for collecting and recycling the plastic packaging they introduce into the market. The guidelines also

introduced targets for recycling and for the reuse of rigid plastic packaging, encouraging industry participation in circular supply chains. In 2025, further amendments brought in even more stringent compliance mechanisms. These include mandatory labelling with barcodes or QR codes to enable traceability throughout the plastic lifecycle, as well as category-wise recycled-content targets that will increase year by year to promote the use of recycled materials in packaging. The 2025 changes also strengthened enforcement by linking the duty of registration, reporting and compliance across all PIBOs, including small and medium enterprises, and introduced penalties for non-compliance.

Minimum recycled content requirements have been phased in under EPR obligations, with targets calibrated to packaging type. For example, rigid packaging recycled content is slated to increase in defined steps through 2029, and flexible packaging has its own trajectory to increase recycled input. These policy shifts signal a move from “end-of-pipe” management toward design for recyclability and circular supply chains.

Category	2024-25	2025-26	2026-27	2027-28 & onwards
Category I	50%	60%	70%	80%
Category II	30%	40%	50%	60%
Category III	30%	40%	50%	60%
Category IV	50%	60%	70%	80%

Source: Plastic Waste Management (Amendment) Rules, 2025, MoEFCC

India’s regulatory evolution reflects a global recognition that reliance on conventional, fossil-based plastics is increasingly unsustainable. As producers are held financially accountable for the life cycle impacts of plastics through EPR, compliance costs are rising. Packaging that fails to meet recycled content and traceability standards may face regulatory penalties or restricted market access.

As carbon pricing, extended producer responsibility and recycled content mandates expand worldwide, the implicit environmental cost of fossil-based plastic is becoming more visible. Producers that fail to innovate face rising compliance costs, supply-chain risks and potential loss of competitive

advantage. Economic models increasingly treat the true lifecycle cost of plastics as part of environmental, social and governance (ESG) frameworks, making alternative materials more attractive despite their current price premiums. Investments in research and development are accelerating. Companies are exploring mono-material substitutes for multilayer films, advanced recycling technologies (including chemical recycling) and product designs that facilitate separation and reuse. Policy drivers like India’s recycled content mandates and traceability requirements are increasing market pull for such innovations.

Purpose and Scope of the Report

This report is designed to support informed decision-making on packaging material choices within the Fast-Moving Consumer Goods (FMCG) sector, with a specific focus on flexible packaging formats such as pouches, sachets, single-use glass bottles and other high-volume consumable packaging. These formats represent a significant share of plastic consumption and waste due to their short use life, complex material composition and limited recyclability. Rather than comparing materials at an abstract or policy level, the analysis adopts a unit-level perspective, evaluating packaging options based on functional equivalence and real operating conditions.

Packaging products commonly used in the FMCG market are unbundled and analysed at the level of individual material components. This allows for a direct comparison between conventional plastic-based packaging and emerging alternative materials on a like-for-like functional basis. Targeting alternative material solutions in this segment offers high leverage for reducing plastic pollution, increasing recyclability and meeting regulatory recycled content requirements.

The scope of the report includes an assessment of commonly used packaging materials, covering their physical properties, functional performance, environmental considerations and regulatory relevance. Building on this foundation, the report introduces upcoming alternative packaging materials that are being developed or adopted in response to regulatory pressure, environmental concerns and evolving market expectations.

A central objective of the report is to move beyond binary comparisons of “plastic versus non-plastic” and instead evaluate whether a given material is appropriate for a specific packaging application under real operating conditions. The analysis recognises that packaging performance depends on multiple factors, including product protection, shelf life, cost, scalability, recyclability and compliance with current and emerging regulations. As such, the report does not advocate a single universal material solution, but rather a structured decision framework that aligns material selection with specific use cases and performance requirements.

Packaging Material in Practice

Overview of Material Types.

Packaging materials used in the FMCG sector are selected primarily to meet functional requirements such as product protection, shelf life, machinability and distribution efficiency. In practice, these choices are shaped as much by system conditions as by intrinsic material properties. In India, post-consumption outcomes are strongly shaped by system conditions beyond the control of individual producers. These include the dominance of informal collection and recycling, variable segregation at source, price-driven recovery economics, and uneven access to formal waste processing infrastructure.

Materials that are simple in composition, widely used and capable of being aggregated at scale are more likely to be recovered after use. Conversely, packaging formats that are lightweight, highly dispersed or composed of multiple bonded layers face significant recovery challenges

regardless of their theoretical recyclability. Design elements such as coatings, inks, adhesives and multilayer structures can further affect recovery outcomes, often determining whether a package retains post-use value or exits the system as waste.

Common materials employed across FMCG packaging include plastics such as PET, HDPE, LDPE and polypropylene, as well as non-plastic alternatives including paper-based materials, aluminium and glass. Importantly, these materials are not interchangeable. Their environmental and economic performance varies substantially depending on whether they are deployed in single-use or reuse systems, high- or low-volume formats, and contexts with strong or weak recovery infrastructure. This variability underscores the need to evaluate packaging materials based on their specific use context rather than material category alone.

Overview of Key Packaging Materials

Comparison of common packaging materials: chemical names, properties, packaging forms, and key uses.

PET	HDPE	LDPE	MLP	ALUMINIUM	GLASS	GLASS
						
Polyethylene Terephthalate	High-Density Polyethylene	Low-Density Polyethylene	Multi-Layer Plastics	Material: Aluminium (Al)	Material: Soda-lime glass	Social-ime glass
Key Properties Lightweight, rigid transparent. good gas barrier	Key Properties Rigid, durable. chemical resistant	Key Properties Films, carry-bags, wraps	Key Properties High barrier. lightweight. structurally complex	Key Properties Lightweight. strong-ininitely recyclable	Key Properties Lightweight. strong. infinitely recyclable	Key Properties Inert, rigid, transparent, reusable
Common Packaging Forms Bottles, rigid containers. trays	Common Packaging Forms Bottles. containers, caps	Common Packaging Forms Bottles, containers, caps	Common Packaging Forms Sachets, laminated pouches	Common Packaging Forms Cans, foils. closures	Common Packaging Forms Beverages, food, chemicals	Common Packaging Forms Beverages, food, chemicals
Beverages, food, personal care	Beverages, food	Beverages, food, oils	Beverages, food pharmaceuticals	Beverages, food, closures	Beverages, food, chemicals	Beverages, food, chemicals

Commonly Used Materials in the Packaging Industry

Packaging materials differ significantly in their physical properties, functional performance, and interaction with waste management systems. Materials differ not only in their physical and chemical properties, but also in how they interact with existing production lines, logistics systems, and end-of-life infrastructure. As a result, materials that appear similar at a polymer or material category level can perform

very differently in real-world packaging systems. These differences play a critical role in determining how materials are used, collected, recycled, reused, or lost to the environment, particularly in contexts where informal collection and market-driven recovery systems dominate. Commonly used packaging material used in India are; PET, HDPE, LDPE, MLP, Aluminium, Glass and Paperboard.

Key uses for packaging include;

Material	Common Packaging Formats	Typical FMCG Applications	Material Oveuse	Key Functional Role	Typical Use Life
PET (Polyethylene Terephthalate)	Bottles, jars, thermoformed trays	Beverages, edible oils, sauces, personal care liquids	Single-use beverage bottles	Transparency, gas barrier, strength	Short (days-months)
HDPE (High-Density Polyethylene)	Rigid bottles, jerry cans, containers	Milk, detergents, shampoos, household cleaners	Personal care bottles(shampoo), detergent bottles, without refill option	Chemical resistance, rigidity	Short-medium
LDPE (Low-Density Polyethylene)	Films, liners, carry bags, inner wraps	Food wraps, secondary packaging, sachet layers	Thin carry bags	Flexibility, moisture barrier	Very short
Multi-Layer Plastics (MLP)	Sachets, pouches, laminated films	Snacks, instant foods, shampoo sachets	Single use sachets	High barrier at low cost	Very short
PP (Polypropylene)	Caps, closures, tubs, flexible films	Yogurt cups, lids, snack packaging	Yogurt lids and desert lids	Heat resistance, stiffness	Short
Aluminium	Foils, blister packs, laminates	Pharmaceuticals, coffee, food wraps	Single use wraps	Light and oxygen barrier	Very short
Glass	Bottles, jars	Beverages, sauces, premium foods	One way Beverage bottles	Inertness, reuse potential	Medium-long
Paper / Paperboard	Cartons, boxes, wraps	Dry foods, secondary packaging	Secondary Cartons	Printability, structure	Short

Packaging materials used in the FMCG sector are selected through a balance of functional performance, cost, manufacturability, and market availability. While environmental considerations are becoming increasingly important, material choice in practice continues to be driven by product protection requirements, shelf-life expectations, processing compatibility, and distribution conditions.

Circularity Assessment: What Actually Circulates in India



Circularity in India is determined less by theoretical recyclability and more by system alignment. Materials with stable scrap value, simple composition and established recycling markets are more likely to remain in circulation. Conversely, materials that require complex processing or offer little post-use value tend to exit the system regardless of regulatory intent. As a result, packaging materials that align with informal collection economics, can be aggregated at scale, and have established recycling markets are far more likely to remain in circulation. Conversely, materials that lack post-use value or require complex processing tend to exit the system as waste, regardless of regulatory intent.

A material-level circularity scoring framework was used to translate these real-world interactions into a comparative indicator of long-term viability. Scores reflect alignment with India's prevailing collection, recovery and recycling conditions, rather than compliance status or individual producer behaviour. The objective is not to evaluate regulatory compliance or individual producer performance, but to capture how each material performs within India's prevailing collection, recovery and recycling ecosystem. By translating real-world outcomes into a comparable indicator, the framework supports prioritisation of materials based on their long-term circular viability under current conditions.



Material Scoring Card

Circularity is assessed using a composite scoring framework, structured around key dimensions that determine whether a material remains in productive use or exits the system as waste. Each dimension is scored on a 1–5 scale, normalised, and weighted to reflect its relative importance in the Indian context.

Scores are aggregated to produce a composite circularity score (0–100) for each material. Lower scores indicate greater structural constraints to circularity under current system conditions. Importantly, the score does not reflect not compliance, legality, or individual producer behaviour, but only material recycling capacity and infrastructure for it.

Interpretation of Scores



The circularity score should be interpreted as a relative indicator of long-term material viability:

- **High scores (≥ 70)** indicate materials that are largely aligned with India's market-driven and informal recovery systems.
- **Mid-range/conditional scores (50–70)** indicate materials with partial circularity, where outcomes depend on targeted interventions.
- **Low scores (< 50)** indicate materials that face intrinsic design or economic barriers to circularity and rely on continuous external support to avoid environmental leakage.

Data Sources:

- Scrap market prices: Informal sector trader surveys, waste dealer networks
- Recovery rates: CPCB waste characterization studies, state-level audits
- End-market demand: Secondary materials market pricing, industry interview

Findings from the Circularity Score

Multi-Layer Plastics (MLP)

Indicative circularity score: ~25–30 / 100

MLP exhibits consistently low circularity performance across assessed dimensions.

- **Material design:** Composite, multi-layer structures inhibit mechanical recycling and are inefficient for recycling.
- **Collection dynamics:** Low or negative scrap value limits engagement by informal collectors, resulting in weak and uneven recovery.
- **Recovery outcomes:** Where collected, MLP is predominantly routed to co-processing or waste-to-energy pathways, which do not constitute material circularity.

The low score reflects structural misalignment between MLP and India's recovery ecosystem, rather than gaps in enforcement or awareness. From a system perspective, MLP is not a viable long-term packaging material at scale under current Indian conditions, unless supported by sustained regulatory or financial intervention or redesigned into simpler material formats.

PET (Polyethylene Terephthalate)

Indicative circularity score: ~70–80 / 100

PET demonstrates strong circularity performance relative to other plastics.

- **Material design:** Mono-material composition and established recycling processes enable recovery.
- **Collection dynamics:** Stable scrap value drives widespread informal sector collection across geographies.
- **Recycling ecosystem:** A mature recycling market exists, though dominated by downcycling rather than closed-loop applications.

PET is broadly compatible with India's existing circular economy infrastructure.

The score indicates that PET is a high-performing and scalable material, with further gains achievable through quality improvement, reuse systems, and closed-loop recycling rather than material substitution.

HDPE

Indicative circularity score: 63-70 / 100

HDPE benefits from reasonable scrap value and established recycling pathways.

- **Material design and recycling:** Relatively simple polymer structure and established recycling pathways support recovery.
- **Collection dynamics:** Moderate and stable scrap value sustains informal sector engagement, though collection rates vary by product type and geography.
- **Recycling ecosystem:** HDPE exhibits a similar recycling system like PET.

HDPE can be considered moderately viable under current systems, with circularity outcomes achievable but not guaranteed. Performance remains sensitive to product design choices, contamination levels, and aggregation efficiency.

LDPE

Indicative circularity score: 35-40 / 100

LDPE plastic similar to MLP are least recycled due to low cost recovery and lack of closed loop recycling.

- **Material design:** Thin-film applications and high contamination rates reduce recyclability and processing yields.
- **Collection dynamics:** Low cost recovery and handling challenges limit informal sector participation.
- **Recycling ecosystem:** Recycling pathways are limited and largely restricted to downcycling, with minimal closed-loop potential.

Under current conditions, LDPE remains structurally disadvantaged within India's recovery ecosystem, with circularity outcomes highly dependent on targeted collection, aggregation, and financial support mechanisms.



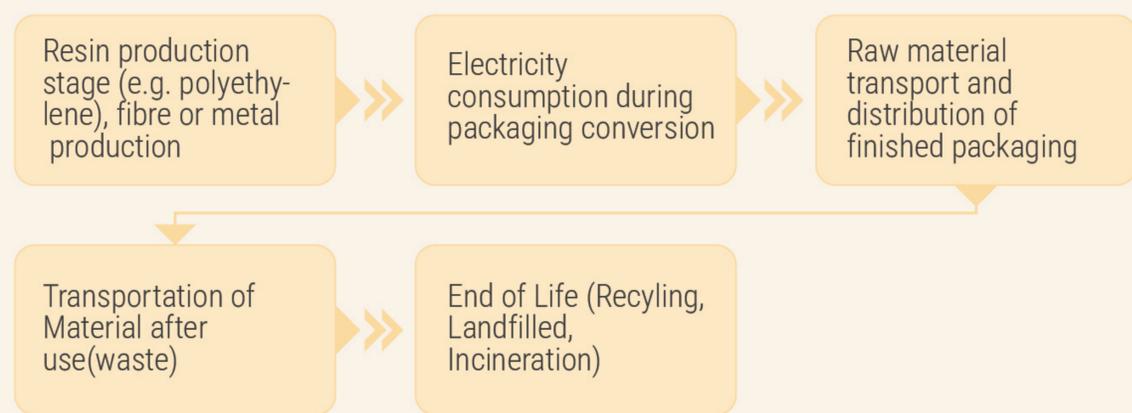
The circularity scorecard indicates that a differentiated material strategy is required, rather than uniform recycling or substitution mandates.

- **High-performing materials (PET, select HDPE applications):** Policy should prioritise system optimisation and closed-loop recycling, with substitution considered only where alternatives can demonstrate superior circularity performance under Indian conditions.
- **Low-performing materials (MLP, LDPE films):** Material substitution, simplification, or elimination of non-essential uses should be central to long-term policy, as recycling-based approaches alone are unlikely to deliver durable circularity outcomes.

While circularity outcomes determine whether materials remain in productive use or exit the system as waste, they represent only one dimension of material sustainability. Materials that circulate efficiently may still carry significant upstream environmental burdens related to raw material extraction, energy use and processing. Conversely, materials that struggle with circularity may offer advantages in terms of reduced fossil dependence or lower production-stage emissions. To fully understand the trade-offs involved in material selection, circularity performance must therefore be considered alongside impacts across the material life cycle.

Life Cycle Assessment of Packaging Materials

Methodology Notes: The indicative lifecycle assessment incorporates the following stages and parameters:



To understand the impact of material better LCA and cost analysis can give a better picture. The life cycle assessment focuses on primary packaging impacts from raw material extraction to end-of-life, including distribution. Secondary packaging, retail energy use, and product loss were excluded due to high variability and lack of consistent India-specific data. These exclusions apply equally to all packaging

systems and therefore do not affect the comparative conclusions. When packaging formats with comparable functional performance are assessed on a per-litre basis, clear differences emerge in their greenhouse gas footprints, shaped by material intensity, energy requirements and end-of-life pathways.

Packaging Type	GHG Emission per bottle kg (CO ₂ e per litre)	Primary Driver	Recycling Offset
MLP	0.32	Fossil-based polymers, no recycling offset	None(Landfilled/incinerated, low recycling)
PET	0.26	Fossil-based resin, processing energy	Lower in case of recycled PET
Paper/Paperboard	0.19	Low material intensity, renewable feedstock	Low (composite structure)
Aluminium	0.76	Energy-intensive primary Al production	High potential if recycled (not realized at scale in India)
Glass	0.91	High material mass, transport intensity	Moderate if recycled; high if reused 10+ times

Lightweight paper-based cartons without aluminium layers exhibit among the lowest climate impacts, driven primarily by low material intensity and comparatively lower emission factors. In contrast, cartons incorporating aluminium layers show noticeably higher emissions despite similar weight, reflecting the high carbon intensity of aluminium production and the absence of effective recycling pathways in India.

Among plastic formats, PET bottles fall within a mid-range impact profile. Their emissions are driven by fossil-based resin production and electricity use during processing, with partial recycling offsetting some, but not all, of the upstream burden. Aluminium packaging displays higher lifecycle emissions per litre, largely due to reliance on primary aluminium, where recycling rates remain insufficient to significantly reduce average impacts. While aluminium offers excellent material recovery potential in theory, reliance on primary aluminium continues to dominate average impacts. Until secondary aluminium consistently replaces virgin input at scale, the climate benefits of recyclability remain only

partially realised. Single-use glass bottles perform least favourably under a single-use assumption. Their high material mass and transport intensity dominate lifecycle emissions, outweighing the benefits of recyclability under current recovery and reuse conditions. Without reuse systems, glass remains structurally disadvantaged for high-volume FMCG applications.

The LCA results highlight that material intensity and upstream production processes are dominant drivers of environmental impact in packaging, often outweighing recyclability in principle. Importantly, lifecycle performance is conditional. PET's relatively favourable outcome depends on continued collection and recycling; paperboard loses advantage when barrier requirements increase material thickness or require coatings; aluminium and glass improve significantly only under reuse scenarios. As such, LCA does not identify a universally superior material, but rather clarifies where trade-offs occur and under what conditions environmental benefits can realistically be achieved.

Cost Analysis and Total Cost of Ownership

This section examines the total cost of ownership of selected packaging materials over extended time horizons, integrating direct material and processing costs with compliance-related expenditures such as Extended Producer Responsibility (EPR) obligations and emissions-linked

charges. The objective is not to identify the lowest-cost material in the short term, but to understand how cost profiles evolve over time and how different materials are exposed to escalation risks.



To understand how these factors interact, the following assessment examines the cumulative cost impact of different packaging materials over a multi-year period. Rather than comparing materials on a per-kilogram basis alone, the analysis reflects the combined effect of material intensity, regulatory compliance requirements and lifecycle-linked costs under Indian operating conditions. Five cost drivers are particularly influential in the Indian context:

- dependence on virgin material inputs,
- ability to incorporate recycled content,
- exposure to EPR compliance gaps,
- processing and waste management requirements, and
- costs associated with emissions and carbon intensity.

The assessment integrates material procurement costs, recycled content obligations, compliance costs, processing expenditures and emission-related costs to reflect realistic operating conditions. When evaluated over a multi-year period, packaging materials exhibit distinct cost exposure profiles driven by differences in virgin material dependence, recycled content compliance, waste processing

requirements and emission-related costs.

While cost outcomes are influenced by multiple interacting factors, presenting a full cost breakdown can obscure rather than clarify material-level differences. For decision-making purposes, it is often more useful to understand how materials compare relative to one another over time, rather than focusing on absolute cost values that are sensitive to assumptions and market volatility. To support a clear comparison across packaging formats, the cumulative cost outcomes are therefore expressed as a relative cost index. This approach integrates material procurement costs, recycled content compliance obligations, waste processing requirements and emission-related costs, while avoiding disclosure of detailed commercial inputs.

PET is used as the reference case (index = 100), reflecting its widespread use and relatively balanced performance under current Indian conditions. Other materials are shown relative to this baseline, indicating the direction and magnitude of cost divergence driven by structural differences in material design, recovery performance and regulatory exposure³.

³For the analysis, per unit cost is considered for material, compliance (EPR and penalties), processing, fixed cost(labour and electricity, machinery),

Material	Relative total cost index(2027)	Relative Cost Index(2032)
PET	100	115
MLP	115–120	140
Paper	130	140
Aluminium	160–170	175
Glass (single-use)	160+	175

The indexed cost comparison highlights that packaging materials with similar functional performance can diverge substantially in cumulative cost over time once regulatory and lifecycle-related factors are accounted for. These differences are not driven by unit material prices alone, but by how each material interacts with recycled content mandates, recovery systems, processing requirements and emissions-related cost exposure.

PET demonstrates the most balanced cost profile across the materials assessed. Partial integration of recycled content moderates compliance gaps and limits reliance on EPR certificate purchases, resulting in a more gradual increase in total system costs relative to other plastic formats. This outcome aligns with PET's comparatively strong circularity performance and mid-range lifecycle emissions. However, PET's relative cost stability is conditional and depends on sustained availability of high-quality recycled resin and continued improvements in recycling efficiency as recycled-content targets rise.

By contrast, multi-layer plastics (MLP) show a disproportionate increase in indexed costs over time despite

low material weight. Persistent dependence on virgin inputs and limited recyclability translate into recurring and escalating EPR compliance costs, which compound as regulatory requirements intensify. These cost pressures are reinforced by higher emissions-related charges associated with end-of-life pathways such as incineration or co-processing. As a result, MLP's short-term cost advantage erodes under longer-term assessment, reflecting its weak circularity and unfavourable lifecycle profile.

Paper-based packaging follows a different cost dynamic. Higher costs are driven primarily by material intensity and processing requirements rather than regulatory penalties. Lower exposure to plastic-specific EPR escalation and comparatively lower lifecycle emissions result in flatter cost growth, although higher material volumes constrain cost competitiveness in high-volume applications. Aluminium and single-use glass remain among the highest-cost options due to energy-intensive primary production, material mass and transport intensity, with limited scope for cost reduction in the absence of reuse systems or high secondary material substitution.



³For the analysis, per unit cost is considered for material, compliance (EPR and penalties), processing, fixed cost(labour and electricity, machinery),

Overall, the analysis indicates that short-term cost rankings are not reliable indicators of long-term economic performance. As regulatory and lifecycle-related costs rise, materials with poor circularity and high environmental intensity become progressively more expensive, while alternatives with higher upfront costs but lower compliance exposure become increasingly comparable. This reinforces the need to evaluate packaging materials through a long-term, risk-adjusted lens rather than static unit-cost comparisons.

Taken together, the cost outcomes reinforce two central insights emerging from the circularity and lifecycle assessments. First, materials that align poorly with recovery systems and rely heavily on virgin inputs tend to accumulate higher and more rigid cost burdens over time. Second, improving recyclability alone is insufficient to ensure cost competitiveness if upstream material intensity or carbon intensity remains high.

Importantly, cost differences observed here should be understood as structural rather than temporary. As recycled

content mandates tighten, traceability requirements expand and environmental costs become more explicit, materials that currently appear marginally competitive are likely to face increasing financial pressure. Conversely, materials that can realistically integrate recycled inputs and reduce lifecycle emissions are better positioned to manage long-term cost exposure.

These findings suggest that optimisation of existing plastic systems, while necessary, will not fully resolve cost and impact challenges for all packaging formats. For materials such as PET and selected rigid plastics, further gains can be achieved through improved recyclability. The combined evidence from circularity performance, lifecycle impacts and cumulative cost outcomes indicates that material choice decisions cannot be resolved through optimisation of existing plastics alone. Where packaging formats demonstrate persistent structural disadvantages across all three dimensions, alternative materials or redesigned packaging formats must be considered as part of a credible transition pathway.

Transition Pathways: Advancing Circular Plastics and Alternative Materials



For materials demonstrating strong or moderate circularity performance, particularly PET and, to a lesser extent, HDPE, the primary policy opportunity lies in transitioning from open-loop and downcycling pathways towards closed-loop recycling systems. Transitioning from open-loop and downcycling pathways toward closed-loop recycling offers tangible environmental and economic benefits. However, these gains remain constrained by practical limitations, including contamination of waste streams, insufficient segregation at source and weak demand-side pull for high-quality, application-specific recycled content.

Key constraints limiting closed-loop outcomes include:

- Quality degradation due to contamination and mixed polymer streams,

- Insufficient segregation at source, and

- Weak demand-side pull for food-grade or application-specific recycled content.

The scorecard simultaneously highlights that not all plastic formats can realistically transition to circular systems, even under strengthened policy frameworks. Materials such as multi-layer plastics and low-value LDPE films exhibit persistent structural barriers, including low economic value, poor compatibility with informal recovery, and limited prospects for closed-loop recycling. Notwithstanding these

constraints, the availability of recycled PET(rPET) and recycled HDPE(rHDPE) remains fundamentally dependent on the continued presence of PET and HDPE in the packaging mix. Abrupt substitution away from these polymers would directly constrain rPET and rHDPE supply, with implications for recycled content targets and secondary materials markets.

In such contexts, continued reliance on circular plastic strategies as the sole response can produce unintended system effects. Over time, this may lead to:

- Prolonged dependence on regulatory support mechanisms to sustain recovery where underlying economics remain weak,

- Diversion of capital and policy attention toward recovery pathways that deliver diminishing environmental and economic returns, and

- Gradual acceptance of non-circular end-of-life outcomes—such as co-processing or energy recovery—as de facto solutions rather than transitional measures.

A credible transition pathway must therefore distinguish between materials that should be optimised within circular systems and those that should be progressively redesigned, reduced or replaced. For such materials, alternative materials or packaging formats should be actively pursued, alongside measures to reduce overall material intensity.

Push toward Circular Plastics and Alternative Plastics

Improving packaging sustainability in India requires a differentiated transition pathway rather than reliance on a single material or strategy. Evidence from circularity performance, lifecycle assessment and cost analysis consistently indicates that packaging materials behave very differently under real system conditions. As a result, a credible transition must distinguish between materials that can be strengthened within circular systems and those that face persistent structural limits.

For materials that already demonstrate strong or moderate alignment with India's recovery ecosystem, particularly PET and, to a certain extent, HDPE, the priority lies in optimisation rather than substitution. These materials benefit from established collection networks, stable scrap value and functioning recycling markets. The primary opportunity is to shift from open-loop and downcycling pathways toward closed-loop recycling, thereby improving material quality, increasing recycled content and reducing lifecycle emissions.

However, even for these materials, closed-loop outcomes remain constrained by practical factors. Contamination of waste streams, insufficient segregation at source and limited demand for high-quality, application-specific recycled content continue to restrict achievable circularity. Addressing these constraints requires coordinated action across design standards, collection systems and demand-side incentives rather than material replacement alone.

In such contexts, continued reliance on circular plastic strategies as the sole response can produce unintended system effects. Over time, this may lead to:

- Prolonged dependence on regulatory support mechanisms to sustain recovery, where underlying economics remain weak

- Diversion of capital and policy attention toward recovery pathways that deliver diminishing environmental and economic returns

- Gradual acceptance of non-circular end-of-life outcomes—such as co-processing or energy recovery as de facto solutions rather than transitional measures

Life-cycle assessments reveal a similar pattern. Early recycling cycles deliver substantial environmental benefits, particularly when high-quality material is recovered and reused in comparable applications. Yet these benefits are not constant across cycles. Polymer degradation, additive

accumulation, and contamination progressively reduce functional performance. Each subsequent cycle yields diminishing environmental returns while requiring greater energy and processing input. The environmental gains captured in initial assessments do not disappear, but they become harder to sustain indefinitely. Over time, plastic does not remain fully circular. It thins out. Material moves from high-value to lower-value applications, from closed loops to open ones, and eventually to uses where recovery is no longer practical or economically viable. At this point, plastic exits managed systems altogether. This process is gradual and often invisible, but it is inherent to the material. No level of policy enforcement or technological improvement can eliminate it.

Behavioural factors amplify this effect. Circular systems depend on continuous human participation—segregation at source, proper disposal, and sustained engagement. Plastic persistence, by contrast, requires no such compliance. Even small lapses in behaviour, repeated across millions of transactions, translate into significant leakage. Informal recovery networks mitigate some of this loss, but they too operate within economic and social constraints. As systems scale, maintaining uniform behavioural performance becomes increasingly difficult.

These realities complicate how environmental sustainability is assessed. Conventional life-cycle tools are well-suited to measuring emissions, energy use, and material efficiency within defined system boundaries. They are less able to capture long-term environmental persistence, microplastic generation, or unmanaged leakage across decades. As a result, materials that perform strongly within modelled life cycles may still generate environmental burdens once they move beyond formal recovery systems. The gap between measured impact and lived environmental reality widens over time.

Circular plastic is best understood as a system that delivers strong returns under specific conditions and within a finite horizon. It is highly effective where material simplicity, economic value, and recovery feasibility align. It is less resilient where products are designed for convenience, consumed rapidly, and dispersed widely. Treating circular plastic as a universal solution across all applications places pressure on systems in ways they were not designed to absorb.

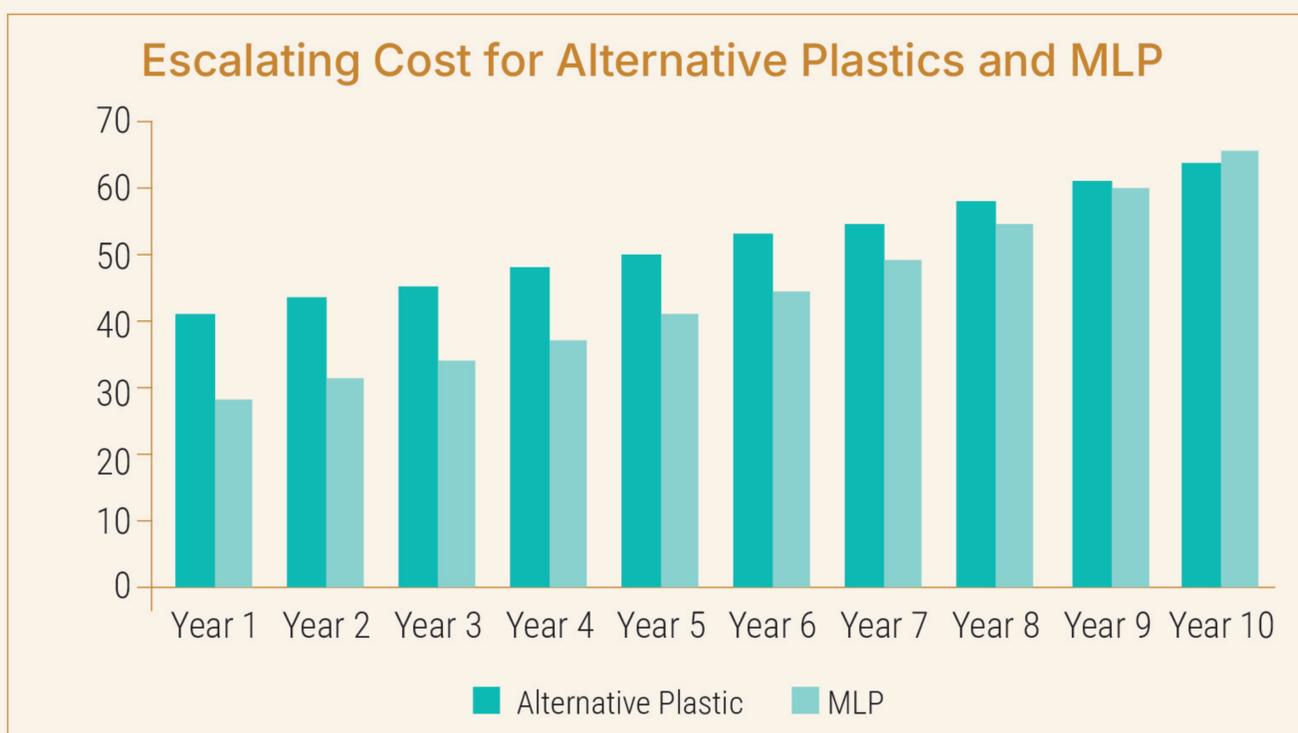
Cost Trajectories and Case for Material Transition

Despite these limitations, the availability of recycled PET (rPET) and recycled HDPE (rHDPE) remains fundamentally dependent on the continued presence of PET and HDPE in the packaging mix. Abrupt substitution away from these polymers would directly constrain recycled material supply, undermining recycled-content targets and destabilising secondary materials markets. This reinforces the need for selective, use-case-specific substitution, rather than wholesale material shifts.

Where circular plastic strategies are applied indiscriminately to structurally weak formats, unintended system effects can emerge over time. These include prolonged dependence on regulatory support to sustain uneconomic recovery pathways, diversion of capital toward low-return recycling

solutions, and gradual normalisation of non-circular end-of-life outcomes such as co-processing or energy recovery. Such outcomes indicate the limits of circularity as a universal response.

The figure below illustrates the comparative cost trajectories of multi-layer plastics and alternative materials over a multi-year horizon. The graph shows that although alternatives carry an initial cost premium, the cost gap narrows over time as regulatory and compliance costs for MLP increase. This convergence does not imply that alternatives become universally cheaper, but it demonstrates that short-term cost advantages of MLP erode under sustained regulatory pressure. However, the costs



Short-term cost comparisons between conventional and alternative packaging materials often favour established plastic formats due to lower upfront material prices and existing processing infrastructure. However, such comparisons do not fully capture how costs evolve over longer time horizons. Over extended periods, compliance and processing costs associated with conventional plastics are expected to increase as Extended Producer Responsibility obligations tighten, recycling targets rise, and enforcement becomes more stringent. Materials with limited circularity, such as multi-layer plastics, are particularly exposed to escalating EPR certificate prices, higher processing requirements, and greater compliance uncertainty. In addition to certificate costs, multi-layer plastics may incur redesign, reformulation, and reporting expenses. Over a ten-year period, these combined pressures could increase cumulative costs by approximately ₹35 lakh

or more, depending on volume and regulatory developments. The relevance of long-term cost convergence becomes more pronounced when environmental performance and export market considerations are incorporated. Alternative materials that demonstrate lower lifecycle emissions and improved end-of-life characteristics are better aligned with emerging requirements in export markets, where packaging sustainability increasingly influences buyer acceptance, compliance costs, and supplier eligibility. While these advantages may not translate into immediate cost savings, they reduce exposure to future regulatory adjustments, redesign requirements, and market-access barriers. Viewed together, stabilising cost trajectories, environmental performance, and export readiness reinforce the strategic case for evaluating alternative materials alongside conventional plastics in applications where long-term risk and leakage concerns are significant.

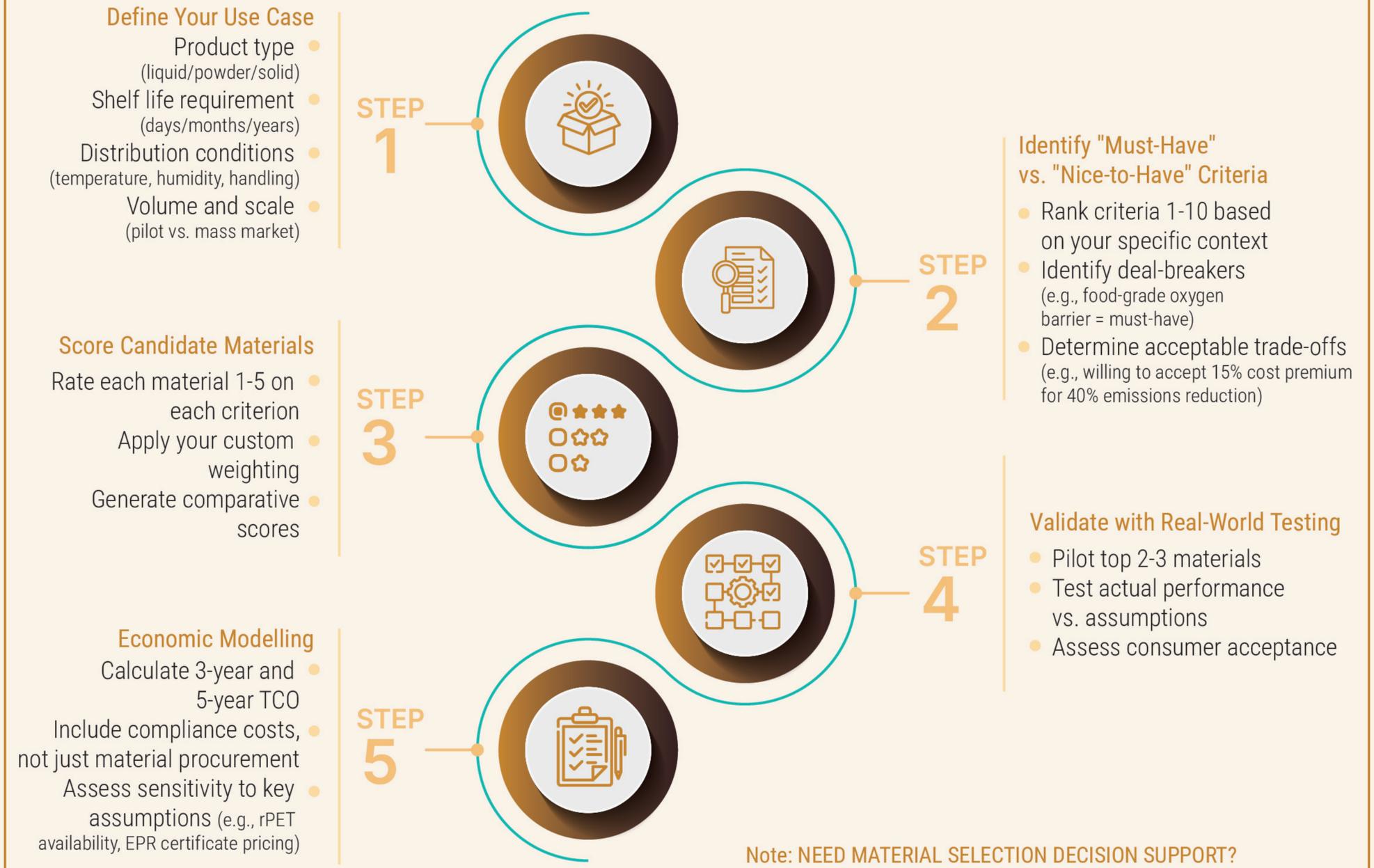
Criteria for Sustainable Packaging Material Selection

Sustainable packaging cannot be defined by a single attribute such as recyclability or bio-based content. Instead, it must be evaluated against a set of interrelated criteria that reflect environmental performance, system compatibility and economic viability under real operating conditions. The question facing packaging systems is not whether one material category should replace another, but how to determine which material is appropriate for a given use case. Material appropriateness requires balancing functional performance, environmental impact, cost exposure and

system compatibility, recognising that trade-offs are unavoidable. The criteria below provide a structured framework for assessing packaging materials based on their suitability for specific applications rather than on material category alone. To ensure that alternative materials are evaluated consistently and in line with the system realities identified above, the following criteria provide a structured framework for assessing sustainable packaging choices across environmental, economic and operational dimensions.

Criteria category	Key question addressed	Why it matters	Typical trade-offs
Functional performance	Does the material adequately protect the product and meet shelf-life requirements?	Packaging failure leads to product loss, which often outweighs packaging impacts	Higher barrier materials may reduce recyclability
Material intensity	How much material is required per functional unit?	Lower material mass generally reduces emissions and transport impacts	Lightweight materials may be harder to collect
Circularity potential	Can the material realistically be collected, recycled or reused at scale?	Determines whether material remains in the economy or becomes waste	High circularity often depends on design simplicity
System compatibility	Is the material aligned with existing collection and processing systems?	Theoretical recyclability does not guarantee real recovery	System misalignment leads to leakage
Lifecycle environmental impact	What are the emissions and energy impacts across production, use and end-of-life?	Prevents shifting impacts upstream or downstream	Low production emissions may come with higher weight
End-of-life outcome	What happens if recovery fails?	Persistence and leakage risk differ across materials	Degradable materials require controlled conditions
Economic viability	Is the material cost-effective over time, including compliance costs?	Determines scalability and adoption	Low-cost materials may carry hidden compliance costs
Regulatory alignment	Does the material meet current and anticipated policy requirements?	Reduces compliance risk and future redesign	Regulations may evolve unevenly
Scalability and supply security	Can the material be produced reliably at required volumes?	Reduces compliance risk and future redesign	Early-stage materials face cost premiums
Behavioural dependence	Does performance rely on consistent consumer action?	Systems dependent on behaviour are fragile at scale	Lower dependence often means higher material cost

How to Use This Framework



Note: NEED MATERIAL SELECTION DECISION SUPPORT?

Adyra ESG Technologies provides:

- Decision framework customization for your product categories
- Material scoring and comparative assessment across 10+ criteria
- Pilot program design and evaluation protocols
- Supplier identification for alternative materials (bio-based, compostable, fibre based)
- Economic modeling (TCO, ROI, payback periods) for material transition

NEED TOTAL COST OF OWNERSHIP MODELING?

Adyra ESG Technologies offers:

- ✓ Custom TCO modeling with your actual procurement data, volumes, and supply chain
- ✓ Scenario planning (best/base/worst case for regulatory changes)
- ✓ Payback period analysis for material transition investments
- ✓ ROI calculations for recycled content partnerships
- ✓ 3-year and 5-year cost projections with sensitivity analysis
- ✓ Turnaround: 3-4 weeks

Overview of Existing Alternate Material for Packaging.

Having established the conditions under which circular plastic systems perform effectively, and the points at which they encounter structural limits, it becomes necessary to examine what material options currently exist beyond conventional fossil-based plastics. The objective at this stage is not to advocate wholesale substitution, but to map the landscape of alternative plastic materials that are already present or emerging in packaging markets.

These materials differ significantly in their feedstock base, functional performance, end-of-life pathways and system dependencies. Some are designed to integrate into existing recycling streams, while others rely on composting, dissolution or controlled degradation mechanisms that require distinct infrastructure and behavioural alignment.

Understanding these differences is critical, as the suitability of alternative plastics depends not on their label, but on how their material properties interact with real-world collection, processing and disposal conditions.

The overview below summarises key categories of alternative plastic materials currently being explored for packaging applications, highlighting their intended end-of-life routes and the primary constraints that shape their practical deployment. This provides a foundation for subsequent evaluation of where such materials may offer a credible complement to circular plastics, and where they introduce new system challenges of their own.

Material category	Typical feedstock	Key applications	End-of-life pathway	Primary limitation
Bio-based plastics (PLA, PHA)	Corn, sugarcane, biomass	Food service ware, films	Industrial composting	Limited composting infrastructure
Bio-PE / Bio-PET	Sugarcane ethanol	Bottles, films	Conventional recycling	Fossil-equivalent persistence
Compostable blends	Starch + polymers	Sachets, liners	Composting	Mis-sorting risk
Fibre-based composites	Paper + coatings	Flexible packaging	Recycling / composting	Barrier performance
Water-soluble polymers	Synthetic / bio blends	Sachets	Dissolution	Niche use cases

The Long-Term Role of Alternative Plastics in Packaging Systems

The overview of alternative plastic materials illustrates that these options are not singular solutions, but a diverse set of materials designed around different assumptions about use, recovery and end-of-life. Their potential contribution lies not in replacing all conventional plastics, but in addressing specific structural weaknesses that persist within existing circular plastic systems.

In the long term, alternative plastics can help reduce environmental risk in applications where conventional plastics consistently fail to remain within managed recovery systems. This includes packaging formats that are short-lived, difficult to collect, highly dispersed, or prone to contamination—conditions under which even well-designed circular plastics struggle to deliver sustained outcomes. In such cases, materials designed for composting, dissolution or benign degradation can reduce the consequences of leakage rather than attempting to prevent leakage entirely.

From a system perspective, the value of alternative plastics lies in risk mitigation rather than optimisation. While circular plastics seek to maximise material recovery and reuse, alternative plastics aim to reduce persistence and long-term environmental burden where recovery is inherently unreliable. This distinction is important: alternative plastics do not need to outperform circular plastics on all metrics to be relevant; they need to perform better in contexts where circularity breaks down.

Over time, a diversified material portfolio by combining optimised circular plastics with targeted use of alternative materials can offer greater system resilience than reliance on a single material strategy. Such diversification reduces pressure on recycling infrastructure, limits dependence on continuous behavioural compliance, and lowers the long-term environmental cost of unavoidable leakage.

Critical Limitation of Alternative Materials

Infrastructure Gaps:

- Industrial composting: Available in <5% of Indian municipalities
- Certification bodies: Limited third-party verification of biodegradability claims
- Consumer awareness: "Compostable" and "biodegradable" often misunderstood (leads to littering)

Performance Trade-offs:

- Most compostable materials have 6–12-month shelf-life limits
- Moisture/heat sensitivity restricts applications
- Barrier properties inferior to conventional multi-layer plastics

Cost Barriers:

- 15-100% cost premiums vs. conventional plastics
- Small production volumes limit economies of scale
- Import dependence creates supply chain risk

Greenwashing Risk:

- "Bio-based" ≠ "biodegradable" (bio-PE persists like fossil PE)
- "Compostable" without infrastructure = landfill
- Certification standards vary globally; limited enforcement in India

Recommendation: Alternative materials are tools for specific problems, not blanket solutions. Use decision criteria framework (previous section) to assess appropriateness for each application.

Implications for Scaling and Policy Design

These cost and demand constraints suggest that alternative plastics should be scaled strategically rather than universally. Early deployment is most credible in applications where conventional plastic systems impose high environmental or compliance costs, or where recovery failure carries disproportionate consequences. In such contexts, higher material costs may be justified by avoided regulatory risk, reduced environmental liability or improved system performance.

Policy design plays a critical role in shaping this transition. Clear standards for end-of-life claims, targeted incentives for high-leakage applications, and alignment between material

choice and waste management infrastructure can help reduce uncertainty and stimulate demand. Conversely, indiscriminate promotion of alternative plastics without system alignment risks repeating the challenges observed with hard-to-recycle conventional plastics.

In the longer term, increased demand, learning effects and infrastructure development may reduce cost differentials and improve performance. However, these outcomes are not automatic. Without deliberate alignment between material design, market demand and end-of-life systems, alternative plastics risk remaining niche solutions rather than scalable complements to circular plastic strategies.

Policy Recommendations to Enable Alternative Materials at Scale

For Government (Central & State):

1. Infrastructure Investment

- Mandate industrial composting facilities in cities >500,000 population by 2028
- Include composting in Swachh Bharat Mission 2.0 targets
- Public-private partnerships for composting infrastructure (build-operate-transfer models)

2. Standards & Certification

- Harmonise biodegradability standards (align with ISO 17088, EN 13432)
- Establish BIS certification for compostable packaging (prevent greenwashing)
- Mandate clear labelling: "Industrial Composting Required" vs. "Home Compostable"

3. Economic Incentives

- GST reduction (18% → 12%) for certified compostable packaging in high-leakage applications
- EPR credit multipliers for alternative materials in sachets/single-serve (2x credit vs. conventional)
- Subsidies for domestic bio-plastic manufacturing (reduce import dependence)

4. Demand Aggregation

- Government procurement mandates (e.g., 30% alternative materials in food service contracts by 2027)
- Public sector pilots (railways, defence cafeterias, government offices)

For Industry:

1. Collaborative Infrastructure

- Industry consortia to co-invest in composting infrastructure near manufacturing hubs
- Shared take-back programs for compostable packaging (reduce individual company burden)

2. R&D Investment

- Collaborative research on India-specific formulations (tropical climate, monsoon performance)
- Barrier performance improvements for fiber-based materials
- Cost reduction through domestic feedstock development (cassava, corn starch from agricultural waste)

3. Consumer Education

- Clear on-pack labelling and disposal instructions
- Public awareness campaigns (avoid "compostable = disposable" messaging)
- QR codes linking to disposal infrastructure locators

For Brands:

1. Strategic Deployment

- Use the decision framework (previous section) to identify the highest-value applications
- Start with controlled environments (B2B, food service with take-back) before mass retail
- Avoid premature claims ("100% sustainable packaging") without system readiness

2. Transparency

- Publish lifecycle assessments comparing alternatives to conventional
- Report infrastructure gaps honestly (e.g., "compostable where facilities exist—currently <5% of India")
- Third-party verification of the environmental clause.

Positioning Alternative Plastics Within a Credible Transition



Taken together, these considerations reinforce that alternative plastics are neither a silver bullet nor a temporary trend. Their role is context-specific and dependent on the coordinated development of the system. When deployed, they can make meaningful contributions to long-term sustainability outcomes. When applied indiscriminately, they can also risk adding complexity without delivering commensurate benefits.

A credible transition pathway therefore requires clear differentiation: strengthening circular plastic systems where they work, and selectively introducing alternative plastics where persistence, leakage and recovery limitations undermine circularity. The following section applies this framework to specific packaging use cases, assessing where alternative materials offer a defensible long-term advantage and where optimisation of existing plastics remains the more effective option.

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Adyra ESG Technologies helps organisations translate sustainability commitments into measurable, data-backed outcomes. We work at the intersection of ESG strategy, carbon accounting, and digital enablement to operationalise climate and circular economy transitions.

Our capabilities include ESG maturity assessments, Scope 1–3 emissions measurement, decarbonisation pathway design, sustainable packaging analytics, and end-to-end sustainability data systems aligned with global reporting standards. We support businesses in moving from compliance-driven reporting to performance-driven transformation.

In areas such as packaging and material circularity, we enable organisations to quantify environmental impact, evaluate material alternatives, model carbon implications, and track progress with verifiable metrics.

At Adyra, sustainability is not a narrative. It is a system – measurable, transparent, and execution-focused.